Heart Beat Sensor

Abstract

Implement a Photoplethysmogram (PPG) device for measuring your heart rate and blood pressure. PPG is a simple and low cost and non invasive optical technique that is used to detect blood volume changes in the microvascular bed of tissue. During one cardiac cycle, the blood pressure varies in the artery from systolic (max pressure) to diastolic (min pressure). This is sensed as change in reflected optical signal due to change in optical absorption in the blood vessel or tissue.

Apparatus

- Breadboard
- TCRT5000
- Operational Amplifier: LM324
- Arduino Board
- DC Power Supply
- Digital Oscilloscope
- Resistors of $1\text{K}\Omega, 2\text{K}\Omega, 10\text{K}\Omega, 33\text{K}\Omega, 330\text{K}\Omega,$
- Capacitors of $1\mu F$ and $4.7\mu F$

Theory

PhotoDetector

TCRT5000([2]) is an infrared light emitting diode-phototransistor pair to detect the PPG signal. Following is the pin configuration of it.

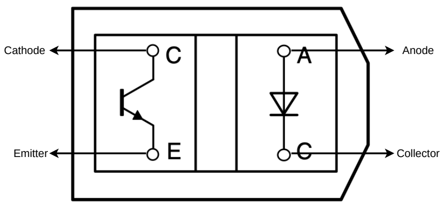


Figure 1.1

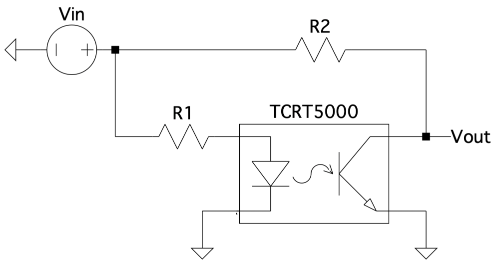


Figure 1.2

Pin	Description
Collector	The collector of the phototransistor is connected to $+5V$
Emitter	The emitter of the phototransistor grounded through a resistor
Anode	The anode of photodiode is connected to $+5V$
Cathode	The cathode of photodiode is grounded through a resistor

The TCRT500 sensor is a combination of a photodiode and phototransistor. The transistor do not have a bias pin because the amount of IR light received by the transistor is responsible for controlling the biasing.

> ⚠️ One's eyes cannot see IR light, so do **NOT** stare into the LED, as large IR power may damage the eyes. To test whether the IR LED is working, one may use the camera of the phone.

The output signal will have a distorted shape but is filled with high frequency noise that needs to be filtered.

Here we took $R_1 = 1\text{K}\Omega$ and $R_2 = 10\text{K}\Omega$.

BandPass Filter

Filters can be classified as

1. High-Pass filter: Filter which lets signals with frequencies higher than the cut-off frequency i.e. the frequency range is $[f_{\text{cut}-\text{off}}, \infty)$
2. Low-Pass filter: Filter which lets signals with frequencies lower than the cut-off frequency i.e. the frequency range is $(0, f_{\text{cut}-\text{off}}]$
3. Band-Pass filter: Filter which lets signals with frequencies in a given range i.e. the frequency range is $[f_1, f_2]$
4. Band-Gap filter: Filter which does not let signals of certain frequency range i.e. the frequency range is $(0, f_1] \cup [f_2, \infty)$

As we know that normal Heart-Beat range is $(30, 180)\text{BPM}$. So, we filtered the output given by the TCRT5000 to an appropriate frequency range, hence created a Band-Pass filter by cascading a High Pass and a Low Pass filter.

$$30\text{BPM} = \frac{30}{60}\text{Hz} = 0.5\text{Hz}$$
$$180\text{BPM} = \frac{180}{60}\text{Hz} = 3\text{Hz}$$

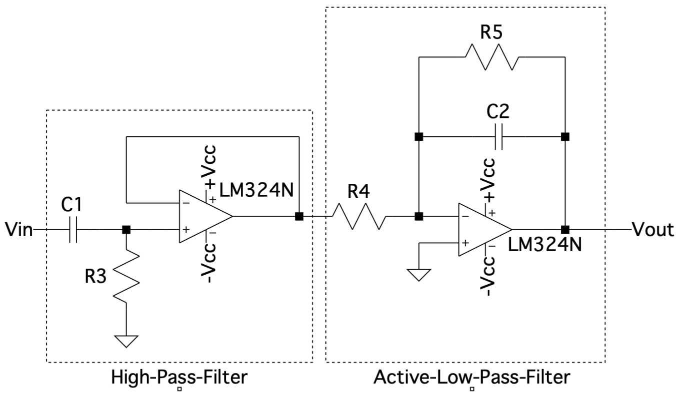


Figure 2.1

R_3	$330\text{K}\Omega$
R_5	$10\text{K}\Omega$
C_1	$1\mu F$
C_2	$4.7\mu F$

For getting the frequency range approximately $(f_{\text{HPF}}, f_{\text{LPF}})$ we used the values of resistance and capacitance as above

$$f_{\text{HPF}} = \frac{1}{2\pi R_3 C_1} = 0.482\text{Hz}$$
$$f_{\text{LPF}} = \frac{1}{2\pi R_5 C_2} = 3.386\text{Hz}$$

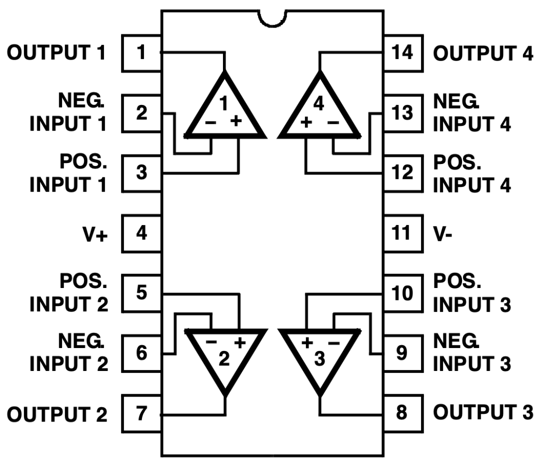


Figure 2.2

So this helps in removing the noise having frequency range as $(0, f_{\text{HPF}}) \cup (f_{\text{LPF}}, \infty)$. Thus, reducing noise in the final output signal.

As it is an active Low Pass Filter, R_4 helps in providing gain to the signal.

$$\text{Gain} = -\frac{R_5}{R_4}$$

Because of the negative sign, the signal gets inverted. We took the value of $R_4 = 1\text{K}\Omega$, resulting in a Gain of -10

For making this filter LM324N operational amplifier([3]) is used. Its pin configuration is as shown in Figure 2.2.

Amplifier and Rectifier

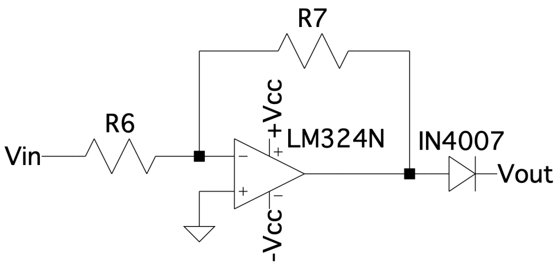


Figure 3.1

The input of the amplifier is the output of the Bandpass filter. The operational amplifier is used to amplify the input signal.

$$\text{Gain} = -\frac{R_7}{R_6}$$

We chose the value of $R_6 = 1\text{K}\Omega$ and $R_7 = 33\text{K}\Omega$, resulting in a Gain of -33

After amplifying the signal, it is rectified using a diode so that the output signal has only non-negative values. This is done because, in the signal we only need the peak and peak frequencies and we do not want to give negative values to the Arduino.

Moreover, the output from the Bandpass is inverted, here the operational amplifier inverts it again and gets the required signal

Processing using Arduino

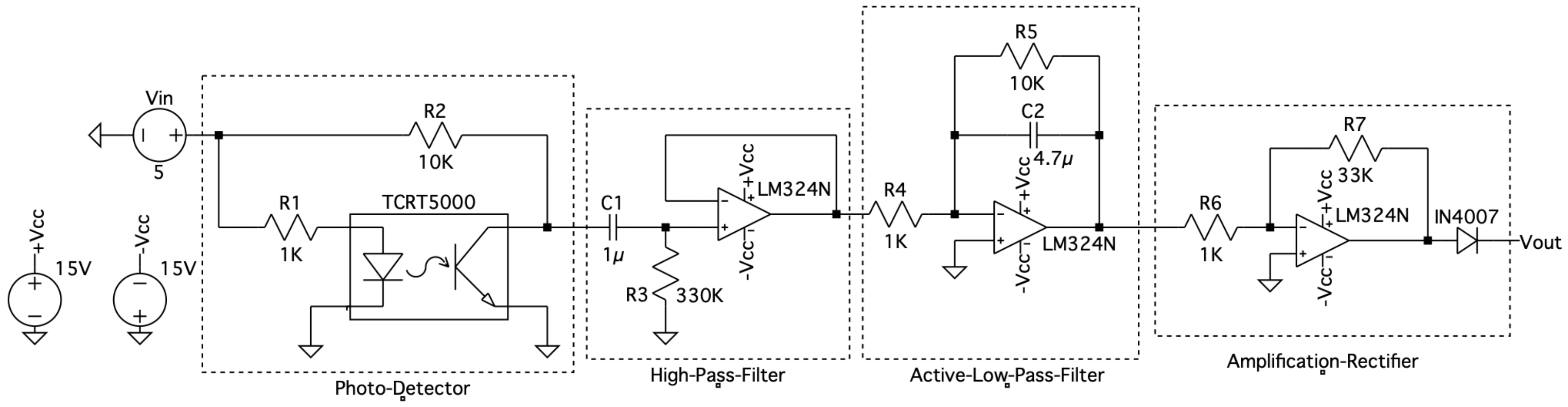
The code is provided in the Github link([1]). The signal output by the rectifier circuit is read by Arduino. Then with a `sampleFrequency = 16` the signal is read. Taking Fast Fourier Transform of the sampled output, we get a peak in the FFT values. The frequency at which the peak occurs is the `peakFreq` . Using it the heart beat is calculated as

$$\text{Heart Rate} = \frac{60 \times \text{samplefrequency} \times \text{peakFrequency}}{\text{samples}}$$

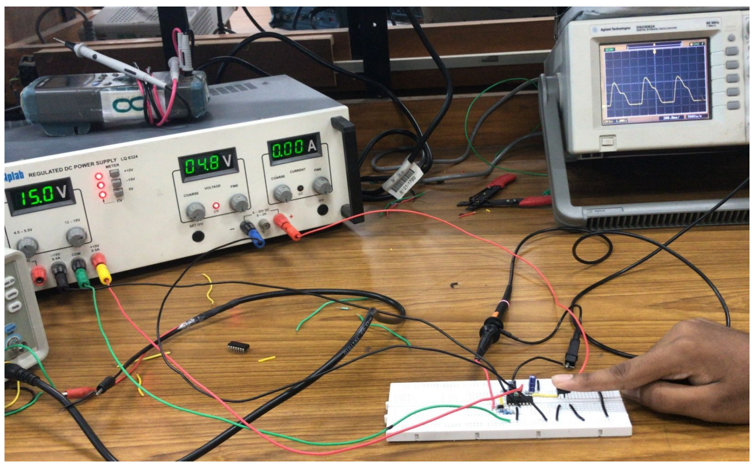
Time delay is calculated as the difference of time of maximum and minimum of time named as `abscissa_max` and `abscissa_min` . Using this Systolic Blood Pressure and Diastolic Blood Pressure are calculated([4]).

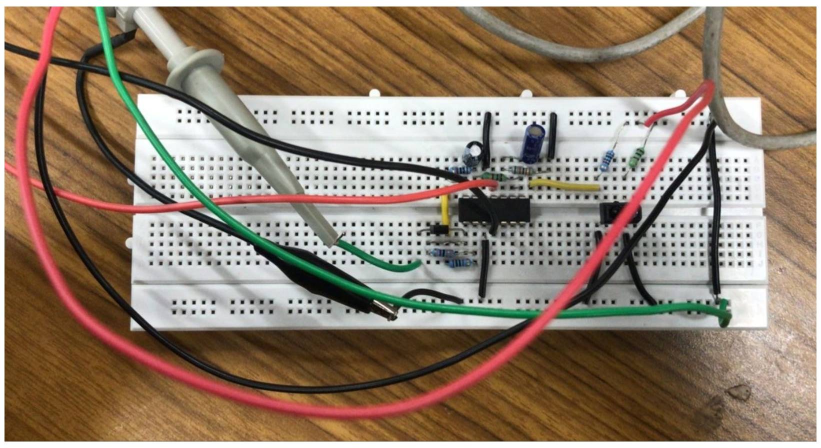
$$\begin{aligned} \text{SBP} &= 184.3 - 1.329 \times \text{Heart Rate} + 0.0848 \times \text{T}_d \\ \text{DBP} &= 55.96 - 0.02912 \times \text{Heart Rate} + 0.02302 \times \text{T}_d \\ \text{T}_d &= \left(\frac{60}{\text{Heart Rate}} - \text{Time Delay} \right) \times 1000 \end{aligned}$$

Arduino Circuit

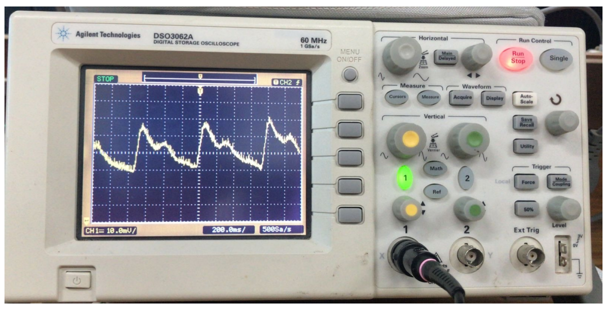


Observations

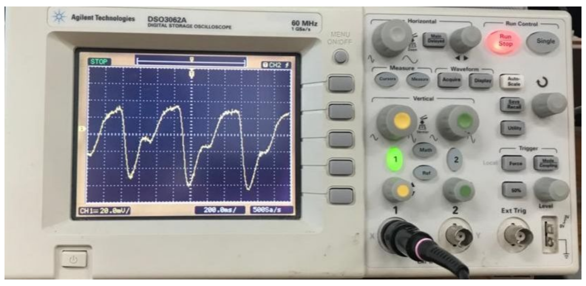




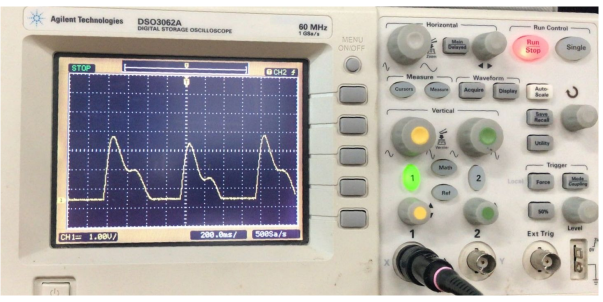
Circuit



TCRT5000 Output



Band Pass Filter Output

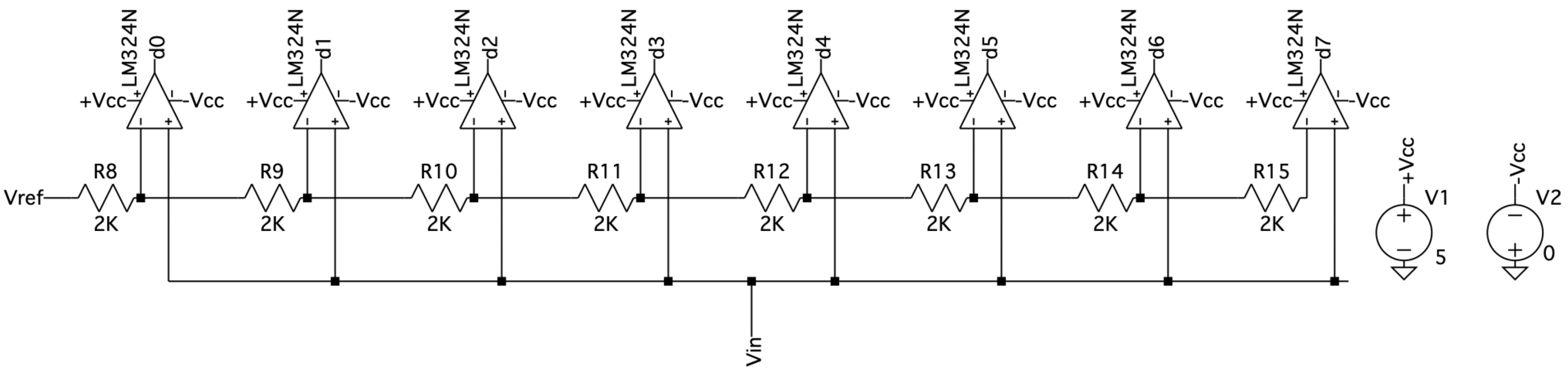


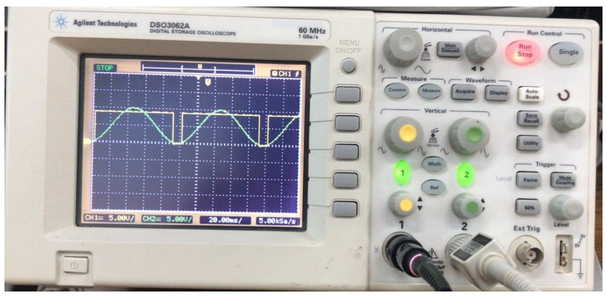
Final Output (Heart Beat)

Providing a video link for the full demonstration of the circuit along with the Arduino Board.

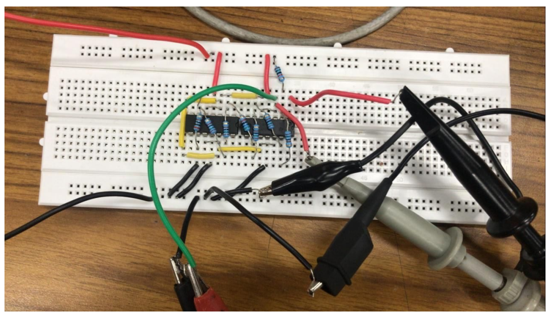
Miscellaneous

$d_0, \cdots, d_7$ are 8 bits. All the resistors have the same value so that the drop across each resistor becomes same. If V_{in} voltage is greater than V_{-} then the bit is `HIGH` otherwise `LOW` . The output of each bit is given to a 3-Bit priority encoder.

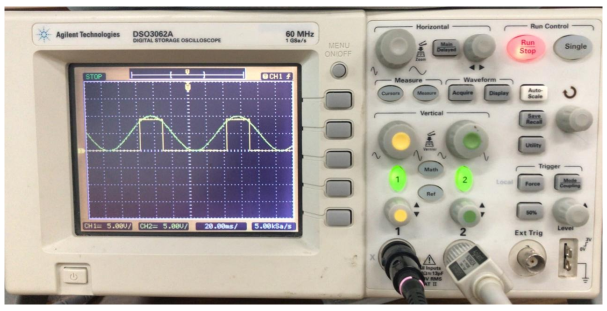




d_1



Comparitor



d_7

D_0	D_1	D_2	D_3	D_4	D_5	D_6	D_7	Q_2	Q_1	Q_0
0	0	0	0	0	0	0	0	0	0	0
X	1	0	0	0	0	0	0	0	0	1
X	X	1	0	0	0	0	0	0	1	0
X	X	X	1	0	0	0	0	0	1	1
X	X	X	X	1	0	0	0	1	0	0
X	X	X	X	X	1	0	0	1	0	1
X	X	X	X	X	X	1	0	1	1	0
X	X	X	X	X	X	X	1	1	1	1

As there wasn't a 3-bit encoder in the lab, we used Arduino to make a 3-bit priority encoder([1]).

Providing a video link for the full demonstration of the circuit using the above comparator.

Conclusion

The signal detected by the TCRT5000 sensor depends on various factors like skin colour, distance of the finger from the sensor. Moreover, as TCRT5000 is a combination of a phototransistor and a photodiode, hence the amount of light that falls on it also changes the reading. The more we increase our sampling rate the more accurate values we get but due to less precision components, high sampling frequency the chances of including the noise component in the output.

Thus, the Heart rate and the Blood Pressure are approximately measured by the circuit. The deviation in values could be due to less precise equipments, bad finger placement etc.

> 📌 Link for Arduino Circuit → link and Comparitor Circuit → link

References

[1] Arduino Code

[2] TCRT5000 Phototransistor datasheet

[3] LM324N Operational Amplifier datasheet

[4] Blood Pressure Formulae

[5] Heart Rate Measurement using PPG